Patterns of the Cranial Venous System from the Comparative Anatomy in Vertebrates

Part II. The Lateral-Ventral Venous System

T. AURBOONYAWAT[1,2], V. PEREIRA[1], T. KRING[1], F. TOULGOAT[1], A. CHUROJANA[3], P. LASJAUNIAS[1]

[1] *Diagnostic and Therapeutic Neuroradiology Service, Hôpital de Bicêtre, Le Kremlin-Bicêtre, Paris, France*
[2] *Division of Neurosurgery, Department of Surgery, Siriraj Hospital, Mahidol University, Thailand*
[3] *Department of Radiology, Siriraj Hospital, Mahidol University, Thailand*

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Summary

Comparing the adult submammalian brain with the human embryonic brain, some patterns of venous drainage are quite similar. The veins lying on the lateral surface of the brain in submammals resemble those of the human embryo. In addition, the new longitudinal venous anastomosis ventral to the brain vesicles occurring late in human embryonic development seems to be similar to the late appearance of the basal vein and the ventral brain stem venous plexus found in adult mammals including man. The evolution of the new structures of the brain vesicles throughout the vertebrate series may have an induction role on the appearance of the cranial venous system.

This part of the article series focuses on the evolution of the lateral-ventral venous system of the five brain vesicles. Nevertheless, the limitation of this article is due in part to the paucity of circumstantial papers and different names used for the veins.

General Introduction

We have already described the dorsal venous system which is mainly involved in draining the neopallium and neocerebellum in vertebrates. This study compares another proposed division of the cranial venous system, the lateral-ventral venous system. This system involves drainage of the paleopallium (or pyriform area), archipallium, archicerebellum and brain stem. All the venous systems which we classified can connect to each other through many anastomoses (Diagram 1).

The lateral-ventral venous system is the system which continues longitudinally from the spinal cord. This study focuses only on the venous drainage of the five brain vesicles because it has a special arrangement. We named the venous system based on the location on the brain.

The recent evolution of this cranial venous system in man includes the cavernous sinus captured from the tentorial sinus, the definitive position of the superior petrosal sinus and its medial drainage into the cavernous sinus.

Materials and Methods

Literature on the cranial venous anatomy in vertebrates was reviewed. Using the area of venous drainage, the veins involved and their functions, we classify the cranial venous system in vertebrates into four systems compared to the venous drainage of the five brain vesicles in man. The vertebrates reviewed are fish (Myxine glutinosa, Eptatretus stouti, and Danio rerio), amphibians (Amblystoma tigerinum), reptiles (Testudo geometrica), birds (Larus argentatus and hen), rodents (inbred Sprague-Daw-

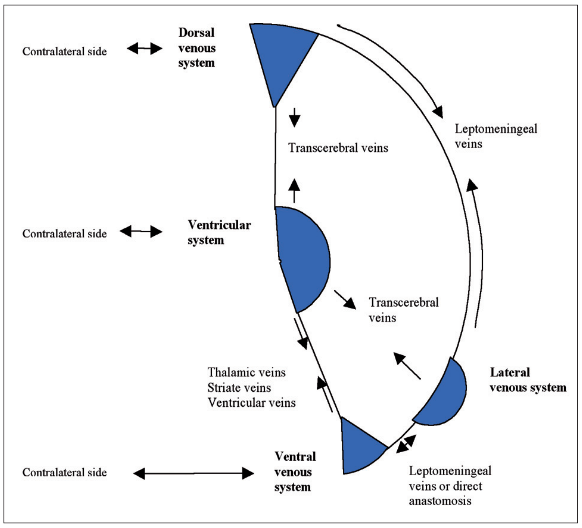

Diagram 1 The venous systems and their connections in man.

ley strain of rats, guinea pigs), tree shrews (Tupaia glis), opossums (Didelphis virginiana), domestic animals (dogs, cats, rabbits, pigs, horses, oxen, sheep and goats) and primates (Macaca mulatta, Cebus paella, Papio ursinus, Cercopithecus pygerithrus, Galago senegalensis).

Results

For the viewpoint of comparative anatomy, we present the lateral-ventral venous system of the brain vesicles separately in two different groups: the lateral and ventral venous groups. When comparing these groups, the lateral venous group seems to be more ancient in evolution. We found this venous group early in submammals when the other group is not well-developed.

Lateral Venous Group

The lateral venous group was labeled based on its position on the lateral surface of the brain vesicles in vertebrates, especially in submammals. From human embryo we include the lateral positioned telencephalic, diencephalic, mesencephalic, metencephalic and myelencephalic veins in this category.

Considering the telencephalic region, we observe a special arrangement of the venous drainage of the paleopallium. With the phylogenic ascent of the brain in vertebrates, the paleopallium is shifted from the dorsal part of the telencephalon in fish to ventromedial position of the telencephalon in man. Using the homologous anatomical position of the venous drainage in different species, it is interesting that the vein moves together with the paleopallium.

Phylogenic Evolution of the Lateral Venous System

Submammals

Fish

The brain vesicles of hagfishes[6] are the large olfactory bulbs, primitive hemispheres, diencephalon, mesencephalon and large medulla oblongata. The areas of the primodial piriform cortex and prepyriform area are drained correspondingly by the "anterior cerebral vein" originating from the ventral telencephalic and diencephalic regions at about the level of the hypophysis and curving around the brain to empty into the "sagittal sinus"(vein).

The "anterior cerebral", "middle cerebral" and "rhombencephalic" veins drain the ventral and lateral surfaces of the diencephalon, mesencephalon, rhombencephalon and mylelencephalon, respectively.

Amphibians

In tiger salamander, Roofe[3] reported that the "vena prosencephali lateralis" receives blood from most of the pyriform area, striatum, diencephalon and a part of the optic tectum. It locates at the dorsolateral surface of the telencephalon and empties into the "rete of the endolymphatic sac" on the dorsal and lateral surfaces of the brain stem.

The veins of the brain stem drain blood from the ventral and ventrolateral surface of the brain stem, and empty into the "endolymphatic rete": the "vena mesencphali", "vena basilaris anterior" and "vena basilaris posterior"

Reptiles

In turtle[2], the corresponding pyriform area is drained by the "anterior and posterior lateral cerebral veins". They locate on the dorsolateral surface of the hemispheres and empty into the "dorsal longitudinal vein". The "diencephalic", "anterior and posterior mesencephalic", and "posterior medullary" veins drain the lateral surface of the diencephalon, mesencephalon, metencephalon and myelencephalon, respectively. They course dorsally and terminate into

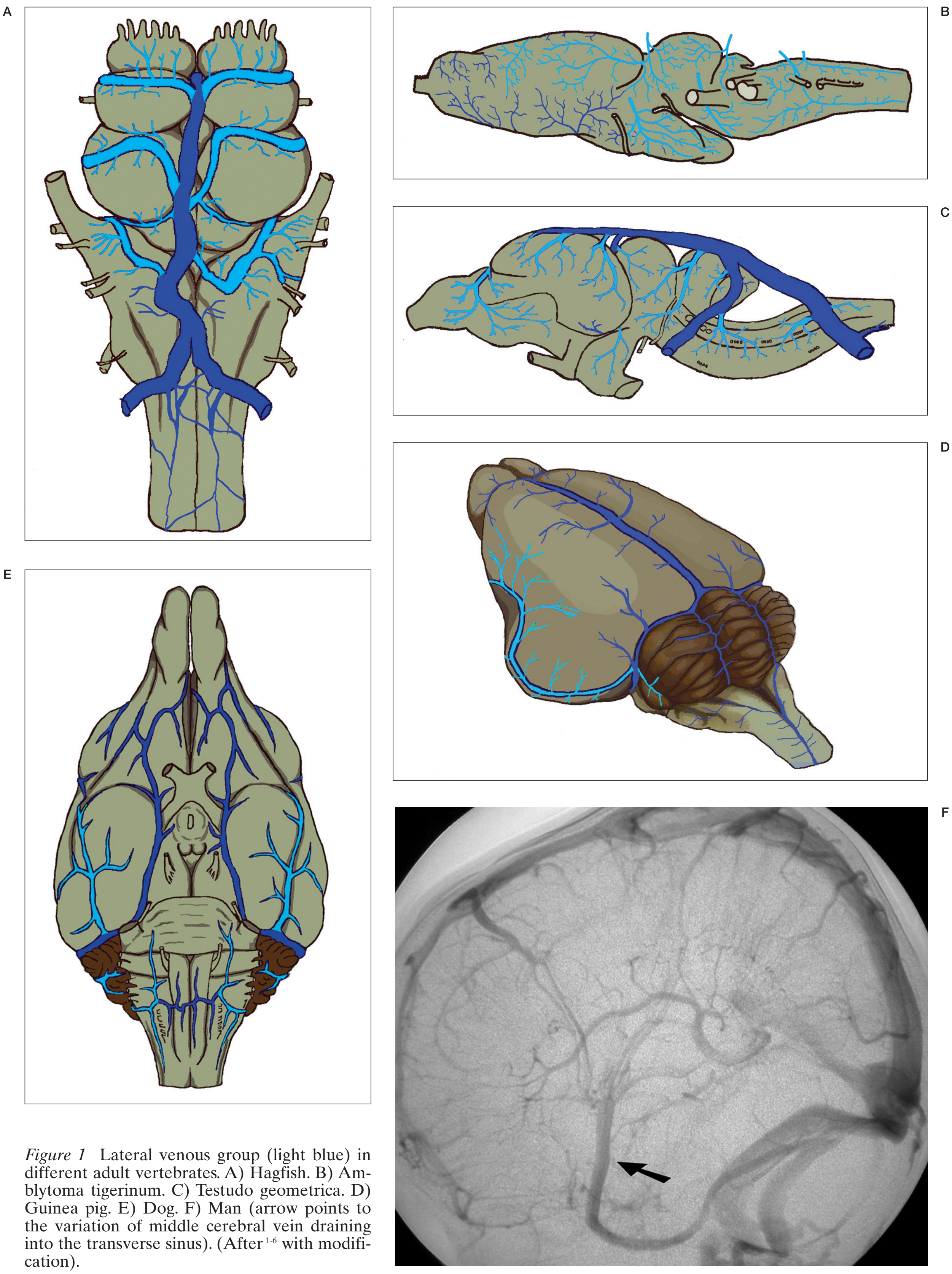

Figure 1 Lateral venous group (light blue) in different adult vertebrates. A) Hagfish. B) Amblytoma tigerinum. C) Testudo geometrica. D) Guinea pig. E) Dog. F) Man (arrow points to the variation of middle cerebral vein draining into the transverse sinus). (After [1-6] with modification).

the "dorsal longitudinal vein" which further connects to the internal jugular vein.

Birds

A homologue of the superior petrosal sinus, the "middle cerebral vein", drains the lateral cerebellum, flocculus and posterior aspect of the tectum, entering the occipital sinus[7].

Mammals

Rodents

On the study of brain vessels in guinea pig[5], the venous blood from the palepallium is likely to be drained into the "superior lateral cerebral vein" which locates on the lateral surface of the telencephalon. It further empties into the transverse sinus as "the vein of flocculus" does.

In rats[8,9], the corresponding pyriform area is drained by the "superficial cerebral vein". It locates on the ventrolateral surface of the hemisphere and empties into the transverse sinus.

Domestic Animals

The "ventral cerebral veins" of domestic animals could be compared to the middle cerebral veins in man. They drain the rhinencephalon and the insular region, course in the rhinal sulcus, and open into the "dorsal petrosal sinus", which seems to be compatible with the tentorial sinus in man.

In horses, the "dorsal petrosal sinus" arises by convergence of small veins in the region of the fossa for the pyriform lobe and the olfactory bulbs. It locates on the ventral surface of the cerebral hemisphere and joins the transverse sinus[4].

In another study of brain venous system of dogs[10], the "ventral cerebral vein" follows the pseudosylvian fissure ventrally, passes caudally in the caudal lateral rhinal sulcus on the ventrolateral surface of the cerebral hemisphere to enter the "dorsal petrosal sinus". It is interesting to note that the role of the lateral venous system in dogs could be shifted from draining the pyriform area to draining the neopallium because the paleopallium is less dominant. For the venous drainage of the cerebellum, the "rostral ventral cerebellar veins" run laterally across the rostral base of the cerebellum and superior cerebellar peduncle. They anastomose with veins of the pons and midbrain, drain parts of brain stem, the paramedian and ansiform lobules of the cerebellum, and empty into the sigmoid or transverse sinuses.

Monkeys

In rhesus monkeys and tufted capuchin, the middle cerebral vein does not drain into the cavernous sinus. The empty site varies among species. That of rhesus monkeys drains into the superior petrosal sinus whereas it drains into the distal transverse sinus in tufted capuchin. The superior petrosal sinus of rhesus monkeys does not communicate with the cavernous sinus. It is relatively short and touches only the lateral part of the petrosal crest[11]. In baboons, vervet monkeys and bushbaby, the superior petrosal sinus becomes apparent half-way along the superior petrous ridge, drains blood into the transverse-sigmoid junction and has also no connection with the cavernous sinus.

Man

Morphological changes in the lateral venous group in neonates after birth are the cavernous sinus capture of the tentorial sinus, and the connection between the superior petrosal sinus and cavernous sinus[11]. The middle cerebral vein in man functions like the neopallium venous drainage. It can empty along the way of the lateral venous system evolution e.g. the cavernous sinus, tentorial sinus, superior petrosal sinus, and even transverse sinus (figure 2).

In the 11-week-old human fetus, the petrosal veins are seen running from the floccular region to the superior petrosal sinus. At this time, its course is totally intradural. Later on the vein unites with the anterior cerebellar veins and the brain stem veins[12].

Hypothesis of the comparative lateral venous group anatomy

Comparing the primitive brain of submammals and the late embryonic human brain, the lateral located veins are similar. We purpose the middle cerebral vein, the tentorial sinus, inferior ventricular vein, lateral mesencephalic-pontine-medullary veins, the petrosal (superior petrosal) vein, and the condyloid (the bridging vein draining the vicinity of medulla) vein as the lateral venous system of the brain vesicles in man.

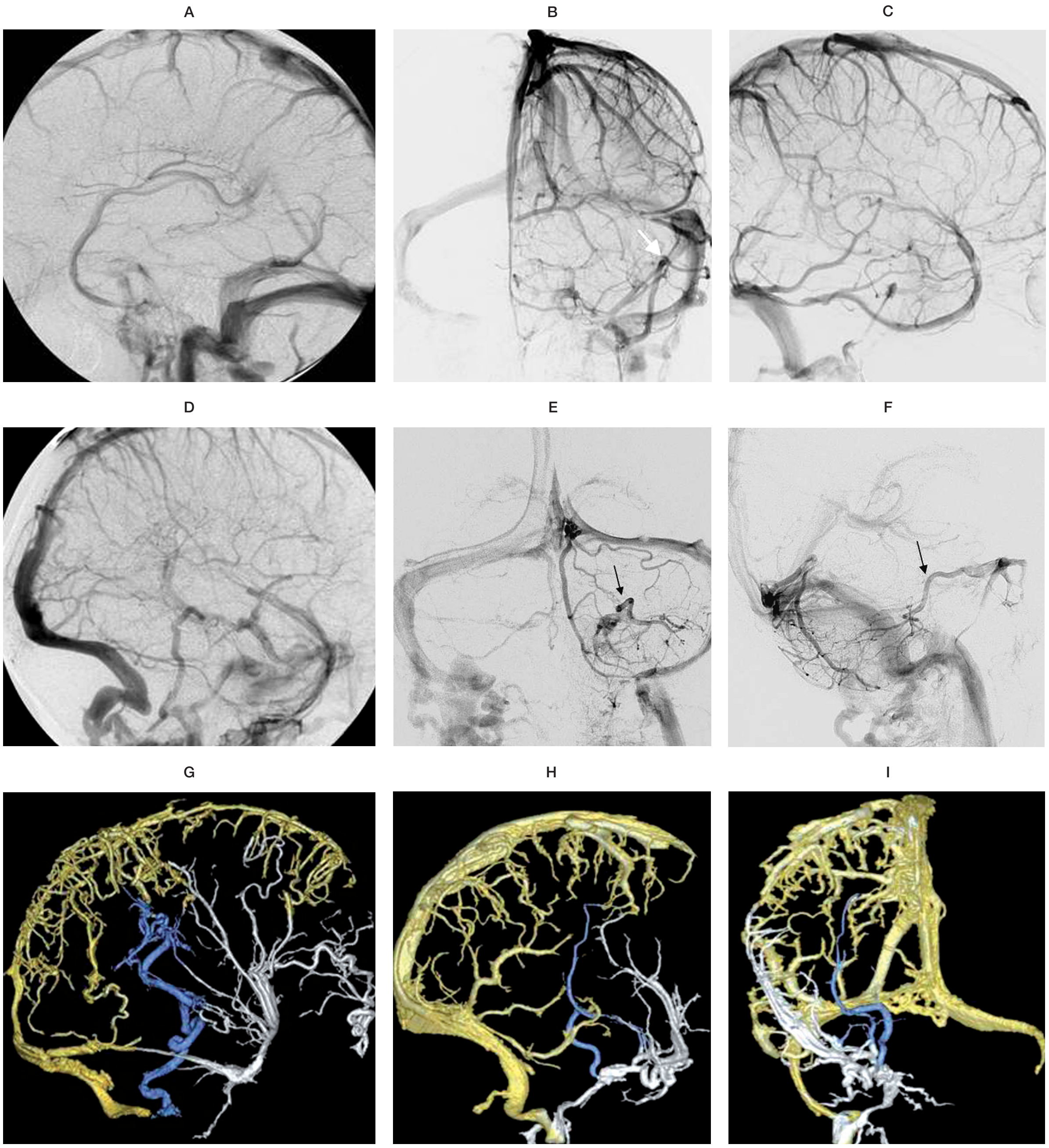

Figure 2 In man, the lateral venous group can empty into several veins or sinuses depending on the way it evolutes phylogenically. The middle cerebral veins can drain into the cavernous sinus (A) and tentorial sinus (white arrow in B), and further into the superior petrosal sinus (G in white) or distal end of transverse sinus (B and C in different views). Subependymal veins can drain into either a fully persistent lateral venous group in the infratentorium (G in blue) or medially into the cavernous sinus via the superior petrosal sinus (H and I in blue). It seems that the petrosal vein draining medially into the cavernous sinus by the way of the superior petrosal sinus (black arrow in E and F) is a new venous evolutional pathway found only in man (D and E).

Their definitive disposition is a new formation phylogenetically.

On evolutionary progression, the paleopallium or pyriform area is moved from the dorsal to ventromedial position. It is interesting to note that the lateral venous system in vertebrates always follows the rhinal fissure. It has a major role in draining the paleopallium. We found that it moves along with the paleopallium from the dorsal position of the hemisphere

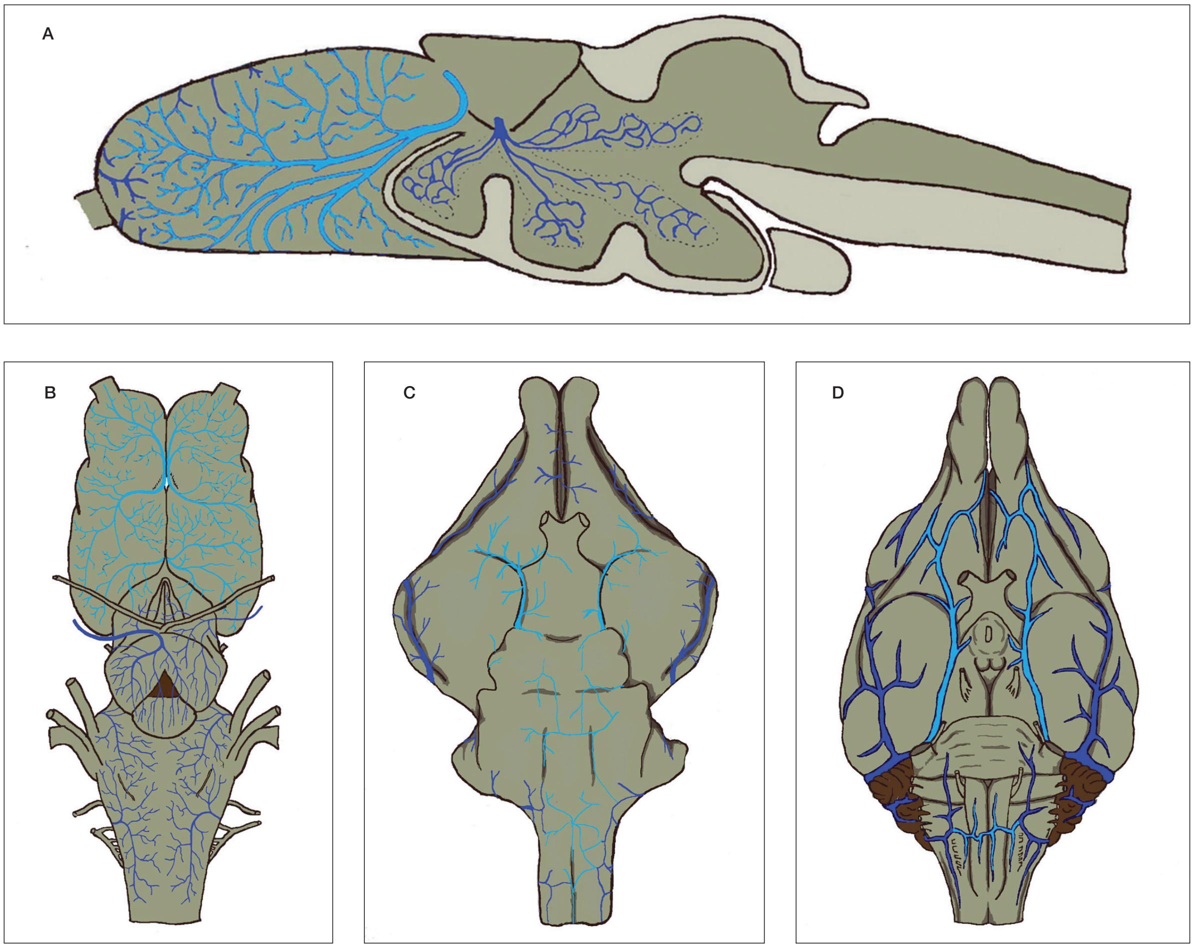

Figure 3 Ventral venous group (light blue) in different adult vertebrate brains. Ventral venous group of the Tiger salamander's brain (A sagittal view: B ventral view) is an example in submammals. This venous group at the telencephalic region is located in the midline whereas this group of the other regions is not well developed. The ventral venous group becomes evident in mammals (C guinea pig; D dog). (After [3-5] with modification).

in fish and amphibians to the lateral position in reptiles [13]. Finally, its function of draining blood from the paleopallium is taken over by the ventral venous group (basal vein of Rosenthal) when the neopallium is dominant in higher vertebrates. This pattern of the "shift in function" is apparent from domestic animals onward. Its role has changed into draining the lateral surface of the neopallium in primates and man. The tentorial sinus in rat, horse, cow and dog lies in the tentorium like that in man.

Having looked at the site of emptying, the comparable lateral venous group in hagfishes, salamanders, and turtles joins with the vein which is the forerunner of the median prosencephalic vein of human embryo, on the mid-dorsal surface of the hemisphere. In tree shrew [14], rats, guinea pigs and domestic animals, it empties into the transverse sinus. In monkeys, it can enter either the superior petrosal sinus or the transverse sinus depending on the species, without connection with the cavernous sinus resembling the tentorial sinus during fetal stages in man.

A homologue of the ventral diencephalic vein in human embryo is the inferior ventricular vein in the adult. For the mesencephalic vein, it is the posterior part of the basal vein of Rosenthal [11]. Looking at the diencephalic and mesencephalic veins in lower vertebrates, they locate on the lateral surface of the diencephalon and optic lobes and drain venous blood into the mid-dorsal located vein which is a homologue of the primitive internal cerebral veins.

The comparable vessel in fish, amphibians and reptiles, of the superior petrosal vein in man is the vein that drains the metencephalon (pons and archicerebellum). Because of almost dorsally oriented venous drainage in lower vertebrates, the comparable "metencephalic veins" of those animals collect venous blood from the ventral part of the metencephalic area and run dorsally near the trigeminal nerve emptying into the "rete of the endolymphatic sac", and the "dorsal longitudinal vein" in Amblystoma, and Testudo, respectively. These veins lie in the comparable subarachnoid space in mammals. The homologue vein of the hen receives venous blood from the lateral cerebellum and dorsal of tectum, and empties into the occipital sinus. It seems that like phylogenic ascent, the metencephalic veins move together with the archicerebellum from the dorsal position in submammals to the lateral position in mammals due to the newly developed neocerebellum. In bat, the sinus is found only by the dural end of the major metencephalic veins. In horses and dogs, the sinus is not in contact with the petrous bone [11]. Armstrong [10] described the homologue of the superior petrosal sinus in dogs, the "rostral ventral cerebellar vein" that anastomoses with the brain stem veins, and dorsal cerebellar veins. It runs laterally across the rostral base of the cerebellum and superior cerebellar peduncle. It is epidural in position when it passes over the ventral paraflocculus and terminates into either the sigmoid sinus or transverse sinus. In monkeys, it touches the bone only in the lateral part and does not communicate with the cavernous sinus.

The condyloid vein can be compared with the vein that drains the medulla oblongata and accompanies the hypoglossal nerve in animals. This vein has changed its direction of drainage from dorsal direction in amphibians and reptiles to ventral direction in higher animals.

Ventral Venous Group

We describe the ventral venous group due to its ventral location on the brain vesicles in vertebrates. This group seems to be well apparent only in mammals due to the induction of the recent acquisition structures on the ventral surface of the brain vesicles such as the neostriatum, the red nuclei, the crus cerebri and the ventral pontine tegmentum. The ventral venous group occurs as the longitudinal venous anastomosis of the lateral venous group. The most cephalic end of this group is interesting. It functions mainly as drainage of the archipallium in lower vertebrates. Like phylogenic ascent, its function and location are gradually changed.

Phylogenic Evolution of Ventral Venous Group

The venous drainage of the olfactory system has changed from a dorsal position into a ventral one. In hagfishes, tiger salamander, tortoise, hen and rats venous blood from olfactory tracts and lobes is drained by the "olfactory veins" and discharged into the dorsal sagittal vein or sinus depending on the species. The pattern of drainage has changed in other mammals by the ventral venous group.

Submammals

In hagfishes [6], the venous drainage of the archipallium is found in the medial surface between the hemispheres. The "middle olfactory vein" originates from the ventromedial surface of the telencephalon and ascends dorsally between the olfactory bulbs receiving blood from the bulbs and the primordium hippocampi. It empties into the "sagittal sinus"(vein).

The primordium hippocampi of the tiger salamander are drained by the "vena hemisphaerii ventromedialis". They locate in between the hemispheres and empty into the "rete of the paraphysis" [3].

The area corresponding to the archipallium in turtle is drained by the "anterior and intermediate medial cerebral veins". They lie on the medial surface of the hemisphere above the level of the interventricular foramen and join the "dorso-medial veins" [2].

Mammals

Domestic Animals

The course and tributaries of drainage of the basal vein of dogs is similar to that of man. But it can anastomose either medially with the great cerebral vein or laterally, a larger one, with the "dorsal petrosal sinus" which could be compared to the tentorial sinus in man. Armstrong et Al [10], found that the "basal vein" of dogs originates as far rostrally as the olfactory bulb, proceeds around the rostral perforated substance and drains the optic tract, inferior ventricular vein of the lateral ventricle, the cerebral peduncle, the tuber cinereum, mamillary bodies, caudal perforated substance and medial geniculate body. Both sides of the basal veins can anastomose through the anastomotic veins as in man. Some rostral territories extend dorsally to the rostral lateral rhinal sulcus and into the pseudosylvian fissure, and drain the rostral pyriform area. One can see that the basal vein of dogs takes over the drainage area of the lateral venous group, the piriform area.

Having looked at the ventral venous group of the infratentorium, the "ventral cerebral vein" in horses, which is homologous to the lateral venous group in man, drains the rhinencephalon and also the ventral brain stem. The small veins from the medulla oblongata and the pons run to either the "basilar sinus" or the homologue of the tentorial sinus in man. The comparable petrosal veins in dogs can drain the brain stem and flow into the sigmoid or occipital sinuses [4].

Man

We consider the ventral longitudinal venous connection from the telencephalon all the way from the ventral brain stem surface to the ventral myelencephalon in human embryo as the ventral venous group. This venous connection can be found in the late embryonic period of human [11].

The formation of the basal vein of Rosenthal in human consists of the anastomosis between the telencephalic, diencephalic and mesencephalic veins [11]. Its existence is sometimes in fragmentary form and possibly found only in mammals. In the usual disposition, it empties into the ventricular system medially. Nevertheless, it can empty laterally into the distal transverse sinus which represents the primary metencephalic vein in the embryo (figure 4).

Hypothesis of the comparative ventral venous group anatomy

As we observed the pattern of the venous drainage of primitive brains of submammals, we found that the first two venous systems which appeared in these animals are the one resulting from the induction of dorsal migration of the gray matter due to cephalization (the ventricular system which will be detailed in the next part of these article series), and the other that lies on the lateral surface of the brain vesicles (the lateral venous group). The ventral venous group develops late in evolution, possibly due to the appearance of the new basal nuclei or white matter tracts such as the neostriatum at the telencephalon, the red nuclei and crus cerebri at the mesencephalon, and the pontine tegmentum at the metencephalon, which need a new venous system to be drained.

Among vertebrates' telencephalons, the evolution and the position of the archipallium are different.

The archipallium is located ventral to the rhinal sulcus in fish, amphibians and reptiles, on the medial surface of telencephalic vesicle. The venous blood is drained into the dorsal midline vein which is assumed to be the forerunner of the median prosencephalic vein of human embryo. When the neopallium and corpus callosum are developed in birds and mammals, it is possible that the pattern of archipallium venous drainage has been changed from the dorsal into ventral pathway, taken over by the development of the veins that continue with the inferior ventricular vein ("ventral diencephlic vein" of human embryo) [11] and the continuous lateral-ventral venous plexus from the brain stem. The newly developed basal vein collects the venous blood from the archipallium, which becomes attenuated in higher vertebrates, emptying mostly in a lateral direction into the transverse sinus and shifting the direction of flow medially into the galenic system with phylogenic ascent. It is located medial and ventral to the rhinal sulcus in man. The former dorsal draining pathway in lower vertebrates regressed leaving the pericallosal veins in the higher ones, which can empty posteriorly into the internal cerebral vein, basal vein or vein of Galen, or anteriorly into the anterior cerebral vein which further drains into the basal vein typically in man. If this venous disposition fully remains all the way along the dorsal surface of the corpus callosum with well-developed basal vein and inferior ventricular vein, one could imagine the limbic arch of the cerebral vein (figure 4A). In chicken, rabbits, guinea pigs, cats, dogs and horses, the basal vein empties laterally into the homologue of the transverse sinus then medially into the vein of Galen. The medial drainage of the basal vein is secondary from the phylogenic standpoint found in certain primates and man [11].

The limbic area in man is drained by several veins around itself (figure 4B). The veins on the paraterminal and paraolfactory gyri drain posteriorly toward the anterior cerebral vein, which empties into the anterior end of the basal vein of Rosenthal. The anterior parts of

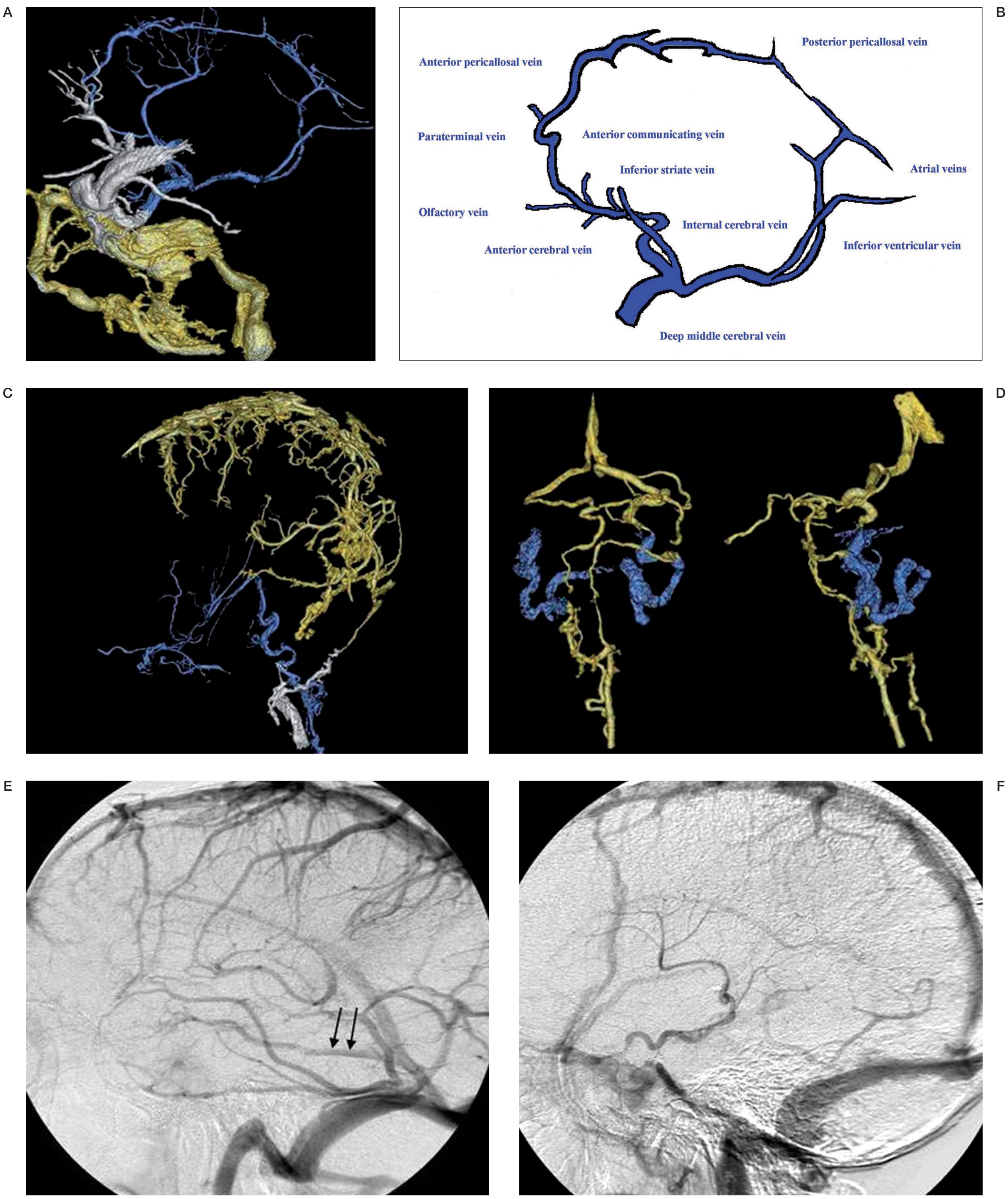

Figure 4 The ventral venous group dispositions in man. A) Fully persistent of the "limbic arch of the vein" is constructed by parts of the pericallosal vein, anterior cerebral vein, basal vein and inferior ventricular vein (blue). B) Illustration shows the arch. C) Dominant ventral venous group takes over from the lateral one (blue). D) The ventral venous group of both supra- and infratentorium (yellow) connects with the lateral one of the metencephalon (blue). E) The ventral venous group (a part of the basal vein of Rosenthal) goes into the lateral group (tentorial sinus, double arrows). F) This system also acts like a connection between the ventricular venous system through the striate veins and the lateral venous system through the deep middle cerebral vein.

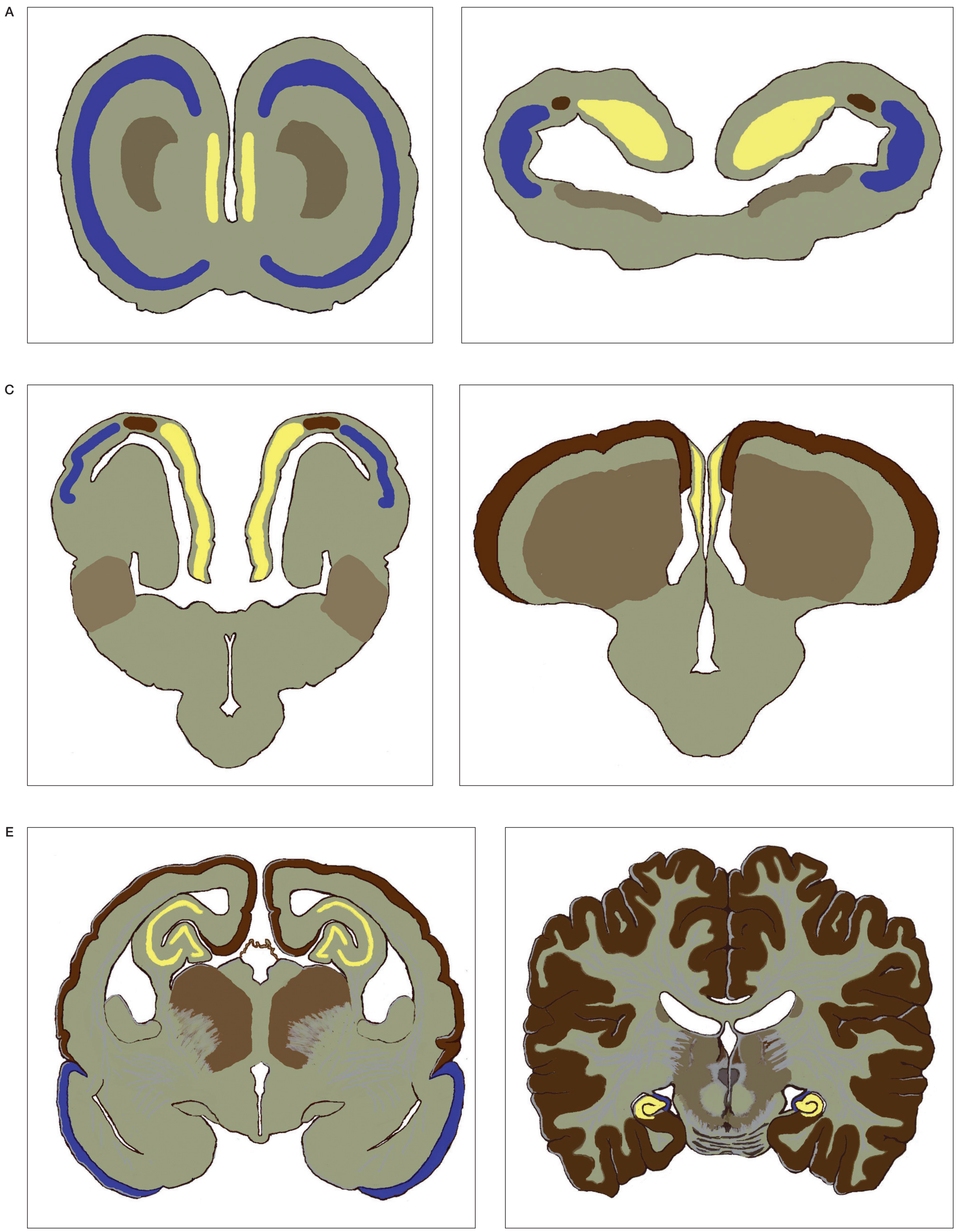

Figure 5 The evolution of the pallia of the brain. A) Hagfish. B) Urodele. C) Turtle. D) Bird. E) Opossum. F) Human (after Elizabeth C.Crosby[13] with modification). Yellow: Archipallium. Blue: Paleopallium. Dark brown: Neopallium. Light brown: Striatum.

the cingulate gyrus and corpus callosum are drained by the anterior pericallosal veins, which may join the inferior sagittal sinus or the anterior cerebral vein. The posterior part of the cingulate gyrus is drained by the posterior pericallosal vein, which drains into the vein of Galen or internal cerebral veins in the quadrigeminal cistern. The area adjoining the isthmus of the cingulate gyrus and the area surrounding the anterior part of the calcarine fissure is drained by anterior calcarine veins, which cross the quadrigeminal cistern to reach the great vein or its tributaries. The medial part of the parahippocampal gyrus and uncus are drained by the uncal, anterior hippocampal, and medial temporal veins, which pass medially to empty into the basal vein of Rosenthal in the crural and ambient cisterns [15].

Ontogenetically [11], when one looks at the embryonic brain vesicles in man, the ventral myelencephalic (the forerunner of the inferior petrosal sinus and hypoglossal emissary vein), ventral metencephalic (the forerunner of superior petrosal sinus and petrosal vein), mesencephalic, ventral diencephalic (the forerunner of inferior ventricular vein), and basal part of telencephalic veins connect together by the "longitudinal veins" as long as through the ventral spinal cord veins. They are the ventral venous group described. Therefore, we can see long venous connections between the basal vein of Rosenthal and the ventral brain stem veins when fully existent (figure 4E).

Considering the ventral venous group in the infratentorial compartment, the ventral venous drainage of the brain stem in lower vertebrates, e.g. fish, amphibians and reptiles, is dorsally oriented. Unfortunately, most of the reviewed articles do not pay much attention to these veins. The available evidence we had shows that the ventral drainage of the brain stem becomes evident in rodents [5] and domestic animals [4] onward. They can have connections with the same system as the supratentorium and the lateral venous group.

Conclusions

It is difficult to compare the evolution of the lateral-ventral venous system among vertebrates because fully descriptive articles are scanty. Having observed the pattern of the venous drainage of the spinal cord in human compared to the brain vesicles in fish, amphibians and reptiles in which the brain is still in a straight line, we found that the lateral-ventral venous system of the brain vesicles in human resembles that of the spinal cord. The disadvantages of this comparative study are barely sufficient descriptive reports with different names for the veins used and the nature of reviewed articles.

References

1 Richards SA: Anatomy of the veins of the head in the domestic fowl. J Zool London, 154: 223-234, 1968.
2 Schepers GWH: The Blood Vascular System of the Brain of Testudo Geometrica. J Anat 73(pt3): 451-495, 1939.
3 Roofe PG: The Endocranial Blood Vessels of Amblystoma Tigerinum. J Comp Neurol 61(2): 257-293, 1934.
4 Ghoshal NG, Koch T, Popesko P: Veins of the head and neck and thoracic wall and thoracic cavity. In: The Venous Drainage of the Domestic Animals. W. B. Saunders Company. 39-93, 1981.
5 Majewska-Michalska E: Vascularization of the brain in guinea pig.I: Gross anatomy of the arteries and veins. Folia Morphol(Warsz) 53(4): 249-268, 1994.
6 Cecon S, Minnich B, Lametschwandtner A: Vascularization of the Brains of the Atlantic and Pacific Hagfishes, Myxine glutinosa and Eptatretus stouti: A Scanning Electron Microscope Study of Vascular Corrosion Casts. J Morphol 253: 51-63, 2002.
7 Pearson R, ed: The Avian Brain. Academic Press Inc: London 27-33, 1972.
8 Szabó K: The Cranial Venous System in the Rat: Anatomical Pattern and Ontogenetic Development I. Basal Drainage. Anat Embryol (Berl) 182: 225-234, 1990.
9 Szabó K: The Cranial Venous System in the Rat: Anatomical Pattern and Ontogenetic Development II.Dorsal Drainage. Ann Anat 177: 313-322, 1995.
10 Armstrong LD, Horowitz A: The Brain Venous System of the Dog. Am J Anat 132: 479-490, 1971.
11 Padget DH: The development of the cranial venous system in man from the viewpoint of comparative anatomy. Contrib Embryol 36: 81-151, 1957.
12 Miquel MA, Mateu JMD, Cusi V, Naidich TP: Embryogenesis of the Veins of the Posterior Fossa: An Overview. In: Hakuba A, Ed Surgery of the Intracranial Venous System. Springer: Tokyo 14-25, 1996.
13 Crosby EC, Schnitzlein HN, ed: Comparative Correlative Neuroanatomy of the Vertebrate Telencephalon. Macmillan Publishing Co, Inc: New York, 1982.
14 Poonkhum R, Pongmayteegul S, Meeratana W et Al: Cerebral Microvascular Architecture in the Common Tree Shrew (Tupaias Glis) Revealed by Plastic Corrosion Casts. Microsc Res Tech 50: 411-418, 2000.
15 Rhoton AL Jr: The Cerebral Veins. Neurosurgery 51 (4 Suppl): S159-205, 2002.

T. Aurboonyawat
Diagnostic and Therapeutic
Neuroradiology Service
Hôpital de Bicêtre
78, Rue du Général Leclerc
F 94275 Le Kremlin-Bicêtre
Cédex Paris, France